

LUSY 7101

Nov 1971

A COMPUTER PROGRAM FOR ACCEPTANCE CALCULATIONS
FOR TWO-BODY PHOTOPRODUCTION REACTIONS

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TYPICAL WORKING TIME

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NATURE OF PHYSICAL PROBLEM:

The program calculates the effective solid angle, the angular and energy distributions, the effective target thickness for incident and emitted particles, the number of interacting photons in a bremsstrahlung beam of one equivalent quantum for two-body photoproduction reactions. For the experimental configuration a cylindrical target with vertical axis irradiated with a beam with a circular cross section and a detector with circular aperture is assumed. For the intensity distribution of the incident beam and the efficiency distribution of the detector empirically determined data can be used.

METHOD OF SOLUTION:

The calculation is performed numerically.

TYPICAL RUNNING TIME:

The running times depend strongly on the size of the experimental set-up and the desired accuracy. The running times for the two test runs are 2.3 minutes and 15.5 minutes respectively (UNIVAC 1108, EXEC II).

experimental set-up from reaction kinematics. Other factors of interest when determining the response function are the incident beam intensity distribution and the efficiency and geometry of the detector.

It is obvious that calculation of all the parameters can only be performed analytically in the few cases in which symmetry considerations simplify the calculation methods.

1. INTRODUCTION

When analysing the results of counter experiments in both nuclear and particle physics the response function of the experimental set-up must be accurately known. This function contains among other parameters the effective target thickness in the beam direction, the effective solid angle subtended by the target at the detector averaged over the incident particle beam and the angular and energy acceptance / distributions. The counting rate at the detector is proportional both to the effective solid angle and the target thickness thus favouring the use of large solid angles and thick targets whenever possible. Large values of these two parameters, however, decrease the energy resolution both because of the larger energy degradation in the target and the lower angular resolution due to the larger number of possible trajectories from the irradiated target nuclei through the angle-defining collimators to the detector. In particular for photoproduction experiments with bremsstrahlung beams these effects have to be carefully considered because one has to determine the incident photon energy and the energy acceptance / distribution of the experimental set-up from reaction kinematics. Other factors of interest when determining the response function are the incident beam intensity distribution and the efficiency and geometry of the detector.

It is obvious that calculation of all the parameters can only be performed analytically in the few cases in which symmetry considerations simplify the calculation methods.

This implies that, in the general case, recourse must be made to numerical methods. This is particularly true for the cases where the input parameters have to be described by empirically-determined data due to irregularities in the incident beam intensity, complicated geometry of the experimental set-up or non-uniformity of the detector efficiency.

In this paper we present a computer program, ACCEPT, written in FORTRAN IV, which treats the general case using empirically-determined input data. The program calculates the effective target thickness for both incident and emitted particles (the latter to facilitate calculation of the energy acceptance in the detector), the effective solid angle and the angular acceptance/distribution for the most commonly-used target-detector configuration. Since the program is primarily intended for photoproduction experiments with bremsstrahlung, it includes sections which calculate the energy acceptance/distribution and the number of interacting photons for an incident photon beam of one equivalent quantum. The energy acceptance calculation is based on the kinematics of a two-body photoproduction reaction. We do not, however, discuss here the effects on the final results of varying the input parameters. Such a discussion would be too extensive if it should cover the range of input parameter values of interest because of the large number of different input parameters possible. Since the program is written in a general manner, it is easily adapted to any particular experimental configuration.

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using empirically-determined input data. The program calculates the effective target thickness for both incident and emitted particles (the latter is facilitated only

existence of the energy acceptance in the detector). The most commonly-used target configurations, some

the program is primarily intended for photoproduction experiments with proton beams, it includes sections which calculate the energy acceptance and the number of interacting photons for an incident proton beam of one equivalent particle. The energy acceptance calculation

is based on the kinematics of a two-body photoproduction reaction. We do not, however, discuss here the effects on the final results of varying the input parameters.

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2. CALCULATION METHOD

2.1 Definitions

We begin by defining some parameters which occur frequently in this paper. The fundamental relation between the counting rate at the detector and the cross-section of the reaction can be written in the following way

$$\frac{d\sigma}{d\Omega} = N_p \frac{1}{t_{\text{eff}}} \frac{1}{\Omega_{\text{eff}}} \frac{1}{n_t} \quad (1)$$

where N_p is the counting rate normalized to the incident flux, t_{eff} is the effective thickness of the target in the beam direction, Ω_{eff} is the effective solid angle of the experimental set-up and n_t is the number of nuclei per cm^3 in the target volume.

The effective target thickness and the effective solid angle are defined as the averages over the target volume and are thus given by

$$t_{\text{eff}} = \frac{\int_{S_t} I_t t_t dS_t}{\int_{S_t} I_t dS_t} \quad (2)$$

and

$$\Omega_{\text{eff}} = \frac{\int_{V_t} I_t \Omega' dV_t}{\int_{V_t} I_t dV_t} \quad (3)$$

respectively. In these formulae, dS_t is a target surface element and S_t is the cross-section of the beam perpendicular to the incident beam direction, I_t is

the incident beam intensity distribution, t_t is the thickness of the target element parallel to the incident beam direction, dV_t is a volume element and V_t is the volume of the target and Ω' is the solid angle element subtended by the detector from the volume element dV_t .

Ω' can be written as

$$\Omega' = \frac{1}{\epsilon_o} \int_{S_d} \epsilon \frac{dS_d}{R^2} \cos\Phi \quad (4)$$

where S_d is the detector surface (cross-section), and dS_d is a surface element of the detector, ϵ is the efficiency of the detector, R the distance from dV_t to dS_d and Φ the angle between the normal $\vec{n}_d$ to dS_d and the line between dV_t and dS_d . ϵ_o is the mean value of the detector efficiency and is given by

$$\epsilon_o = \frac{1}{S_d} \int_{S_d} \epsilon dS_d \quad (5)$$

Due to kinematics, ϵ_o can vary with the energy of the detected particle, an effect which is, however, not considered here. These various definitions are illustrated in figure 1.

The general principle for evaluation of the integrals is the following. The integrals are transformed into finite sums in which each term gives the contribution to the sum from one volume element in the target or one surface element on the detector. The summations are then performed by scanning the entire target volume and (or) the entire detector surface element by element and adding

the contributions as shown in the flow chart of figure 2.

Since we are mainly interested in applications to counter hodoscopes, ACCEPT has been written to apply to the most commonly-met target-detector configuration for liquid target materials, a cylindrical target with vertical axis and a detector with a circular aperture as shown in figure 1. With solid target materials a plane-parallel target is often more suitable. To adapt the program to the latter case some minor changes due to the different geometrical conditions have to be made (see Ref [1]). These trivial modifications do not however change the main principles of the calculation outlined here.

We assume further that the incident beam is horizontal with a circular cross-section, that the detector which also lies in the horizontal plane is not traversed by the incident beam and that the target is sufficiently thin so the absorption of the incident beam can be neglected.

2.1 Calculation of Ω'

In the following we treat only the case in which the detector is circular and has constant efficiency i.e. $\epsilon = 1$. It is trivial to make some minor changes to adjust the program for the case in which the efficiency of the detector is variable but has circular symmetry. One needs only calculate the solid angle for different values of the detector radius and then perform a suitable weighting. The case in which the detector efficiency is asymmetrical can also be treated, in which case the calculation must be

performed numerically, following the more computer time consuming method used for calculating the angular acceptance distribution given in section 2.4.

The problem of evaluating the integral in (4) is thus reduced to calculating the purely geometrical solid angle element subtended by a plane circular detector from an arbitrary point in the target. As is shown in Ref [2], such an element can be expressed as an infinite geometrical series as follows:

$$\Omega' = 4\pi \left[\frac{1}{2} \left(1 - \frac{z}{r_o} \right) + \frac{1}{2} \frac{z}{r_o} \sum_{n=1}^{\infty} \frac{(-1)^n (2n+1)!}{2^{4n} (n!)^2} \left(\frac{\rho}{r_o} \right)^n \sum_{k=0}^n m_k \right] \quad (6)$$

where

$$r_o = \sqrt{R_d^2 + z^2}$$

and

$$m_k = \frac{(-1)^{k+1} (4n-2k)!}{(2n-k)! (2n-2k+1)! k!} \left(\frac{z^2}{r_o^2} \right)^{n-k} \quad (7)$$

In these formulae, R_d is the radius of the circular detector, z is the distance from the point P selected in the target to the detector plane and ρ is the distance from that point to the axis of the detector as shown in figure 3. The series expansion is valid for $\rho/r_o \ll 1$, which is always fulfilled in our applications. In the experimental configuration for which calculations have been performed it has been sufficient to use only two or three terms of the expansion, because of the rapid decrease in magnitude of consecutive terms.

2.3 Calculation of t_{eff} and Ω_{eff}

The centre of the target is indicated as TCM in figure 4. The position of a point P_1 in the target is given as shown in fig 5 by its distance y to the horizontal plane through TCM, the distance d_0 to the vertical plane through TCM parallel to the incident beam and the distance x_0 to the vertical plane through TCM perpendicular to the beam as shown in fig 4 direction. Because of symmetry, four points P_1 , P_2 , P_3 and P_4 are treated together. These points, whose projections on the horizontal plane through TCM are marked P'_1 , P'_2 , P'_3 and P'_4 in figure 4, are mirror points of one another relative to the vertical axis through TCM. To save space we outline here in this paper the calculation method for point P_1 only. For the other points the treatment is essentially the same, with allowance for the different geometrical conditions.

of t_{eff} and Ω_{eff} as
The calculation/outlined in section 2.1 is performed in three steps, each corresponding to one of the three distances (coordinates) defined above. A d_0 -loop with increment Δd and limiting values $\Delta d/2$ and $(d_0)_{\text{max}}$ encloses a x_0 -loop with increment Δx and limiting values $\Delta x/2$ and $(x_0)_{\text{max}}$ which in turn encloses a y -loop with increment Δy and limiting values $\Delta y/2$ and $(y)_{\text{max}}$. For the upper limits, one finds for the target configuration used, the following expressions:

$$(d_0)_{\text{max}} = R_b$$

where R_b is the radius of the incident beam at the target,

$$(x_0)_{\text{max}} = \sqrt{R_t^2 - d_0^2}$$

where R_t is the radius of the target cylinder, and

$$(y)_{\max} = \sqrt{R_b^2 - d_0^2}$$

The volume element (summation element) at the point P_1 is

$\Delta v = \Delta d \Delta x \Delta y$. The element is multiplied by two factors to yield the corrected volume element

$$\Delta v_c = \Delta v f_{ct} I_t$$

The first factor f_{ct} determines the fraction of the volume element which lies inside the irradiated target volume, while the second I_t is the intensity of the incident beam at the point P_1 . The target has been implicitly assumed to have constant density. If this is not the case, a density-correcting factor should be included in eqns (2) and (3) and consequently in the expression for Δv_c . The variation of the beam intensity is given by numerical input data as discussed in the introduction. In the version of the program presented here the beam is assumed to be symmetrical around its centre.

Adding all the corrected volume elements Δv_c gives the numerator in eqn (2). A similar calculation gives the denominator. The effective target thickness t_{eff} is then obtained as the quotient between these two quantities.

The calculation of the effective solid angle Ω_{eff} is performed similarly.

The distance from the point P_1 to the detector plane is, as shown in figure 4, given by

$$z_1' = z_0 - (z_1 - z_2)$$

where z is the distance from TCM to the centre of the

detector, and

$$z_1 = d_1 \cos \theta$$

where θ is the detector angle relative to the incident beam with

$$d_1 = \frac{d_0}{\sin \theta}$$

and

$$z_2 = x_0 \cos \theta$$

The distance ρ_1 from P_1 to the line from TCM to the centre of the detector is

$$\rho_1 = \sqrt{(d_2 + x)^2 + y^2}$$

where

$$d_2 = d_0 \cos \theta$$

and

$$x = x_0 \sin \theta$$

The solid angle element Ω' subtended by the detector from the point is then given by

$$\Omega' = SA(R_d, z'_1, \rho_1)$$

where SA is the function that gives the value of the solid angle element according to eqn (6) and the effective solid angle Ω_{eff} is obtained from eqn (2). To study the variation of the solid angle elements throughout the target volume, the maximum and minimum solid angle elements with their coordinates are calculated.

2.4 Calculation of the angular acceptance

It was mentioned in the introduction that the solid angle and the angular acceptance in the detector are directly-connected to each other. The angular region from $\theta_{\min}$ to $\theta_{\max}$ around θ in which particles from the target can be emitted and accepted by the detector is shown in figure 4.

As before, the calculation method is outlined for only the point P_1 in the target. The treatment is in principle similar for the other points. The cross-section of the circular detector is divided into a number of surface elements of widths $d(R_d)_x$ horizontally and $d(R_d)_y$ vertically. The element is shown as the shaded area in figure 5. In the calculation for every volume element in the target, the entire area of the detector is scanned through systematically and for each surface element on the detector the angle θ' in the reaction plane between the incident beam direction and the line from the target element to the detector element is calculated. As can be seen from figs 4 and 5, the angle θ' can be calculated by using

$$\theta' = \text{atan} \frac{a'}{b}$$

where

$$a' = \sqrt{a^2 + (y + (R_d)_{y\max} / 2 - (R_d)_y)^2}$$

with

$$\begin{aligned} (R_d)_{y\max} &= 2 \sqrt{R_d^2 + (R_d - (R_d)_x)^2} \\ a &= z_0 \sin\theta - d_0 - (R_d - (R_d)_x) \cos\theta \end{aligned}$$

and

$$b = z_0 \cos\theta + x_0 + (R_d - (R_d)_x) \sin\theta$$

The probability for a value of the angle θ' is proportional to the solid angle subtended by the detector surface element from the point P_1 in the target and can according to figure 5 be given by

$$p = \frac{d(R_d)_x d(R_d)_y z'_1}{c'^3} f_{cd} I_t$$

where f_{cd} is the factor which determines the fraction of the detector surface element which lies inside the detector surface, I_t is the incident beam intensity at the point P_1 in the target and

$$c' = \sqrt{z'^2_1 + v^2 + (y + (R_d)_{y\max}/2 - (R_d)_y)^2}$$

where

$$v = |(R_d)_x - R_d - x + d_2|$$

as can be seen from figure 4.

If the detector efficiency is not constant, the factor ϵ defined in eqns (4) and (5) should be included in the probability formula.

For each value of the emission angle, the calculated probability is stored in a histogram which, when the entire target is scanned, gives the distribution of the angular acceptance $D_a(\theta)$ of the experimental set-up. The mean value of the distribution is the mean emission angle θ_m .

2.5 Calculation of the effective target thickness for the particles emitted

In bremsstrahlung-induced photoproduction reactions with two particles in the final state

one determines the photon energy acceptance from reaction kinematics. As the kinematical calculation implies knowledge of the distribution of the emitted particle energies E_p , the spread in energy loss for particles produced at various points due to different trajectory lengths in the target volume has to be taken into consideration. The calculation method is outlined for the point P_1 in the target. The part of the particle trajectory which lies inside the target volume is t_p and its projection on the horizontal plane t_h . As can be seen from figures 5 and 6,

$$t_p = t_h / \cos \beta$$

where

$$\beta = \text{atan} \frac{y + (R_d)_{y\text{max}} / 2 - (R_d)_y}{c}$$

and

$$t_h = \sqrt{R_s^2 + R_t^2 - 2R_s R_t \cos \alpha}$$

with

$$\alpha = \pi - (\theta_d + \text{atan} \frac{d_0}{x_0} + \alpha_1)$$

α_1 being given by

$$\sin \alpha_1 = \frac{R_s}{R_t} \sin(\theta_d + \text{atan} \frac{d_0}{x_0})$$

For every element at the detector surface the corresponding trajectory length in the target volume and its relative probability is computed following the same method used for the angular acceptance calculation as outlined in section 2.4. The distribution of the final

accumulated probabilities give the trajectory distribution.

In calculating the energy distribution $D_e(E_p)$ of the emitted particles, one can use the entire trajectory distribution or, an approximation which is often sufficiently accurate, the mean value of the distribution which is then taken to be the effective target thickness traversed by the emitted particles. Since the calculation of the energy resolution function for the detector depends on its details, the other programs used has not been included here. Instead, energy distribution is treated as input data (Ref [3]).

2.6 Calculation of the energy acceptance of a bremsstrahlung beam for a two-body final-state reaction

To calculate the energy acceptance of the incident bremsstrahlung beam for normalization of N_p in eqn (1), the angular and energy distributions of the particles emitted are scanned through systematically so all possible combinations of angle and energy values are covered. For every pair of angles θ and energies E_p the corresponding photon energy k is calculated, and a relative probability $P(k)$ is assigned to the value of the photon energy obtained. This probability is defined as

$$P(k) = D_a(\theta)D_e(E_p)$$

where $D_a(\theta)$ and $D_e(E_p)$ are the angular and energy distributions of the particles emitted as given in sections 2.4 and 2.5. The probability of the photon

energy is stored in a photon acceptance histogram, the final accumulated content of which gives the photon acceptance distribution $p_{acc}(k)$ of the experimental set-up. The obtained photon acceptance distribution is finally normalized against the number of equivalent quanta Q in the incident photon beam. The quantity Q is related to the total energy content U in the bremsstrahlung beam by

$$U = \int_0^{E_0} n(k, E_0) k \, dk$$

with

$$Q = \frac{U}{E_0}$$

where $n(k, E_0)$ is the number of photons with energy k and E_0 is the bremsstrahlung end point energy. For the distribution $n(k, E_0)$, the Schiff spectrum for a thin Pt-target (Ref [4]) is used. The number of interacting photons per equivalent quantum is then calculated using

$$N_{ph} = \int_{k_{min}}^{\max(k_{max}, E_0)} B(k, E_0) \cdot p_{acc}(k) / k p_{acc}(k)_{max} \, dk$$

where $B(k, E_0)$ is the normalized bremsstrahlung spectrum defined by

$$B(k, E_0) = \frac{1}{Q} n(k, E_0) k$$

k_{min} is the minimum and k_{max} is the maximum accepted photon energy, $\max(k_{max}, E_0)$ is the larger of k_{max} and E_0 , and $p_{acc}(k)_{max}$ is the maximum value of the photon acceptance distribution.

3. THE PROGRAM

3.1. The subprograms

Besides standard Fortran library function subprograms the subprograms listed below are used. To save space a detailed description of the calling sequences, the detailed operations and the parameters used in each subprogram are contained on comment cards at the head of each subprogram. Here we give only a brief review.

- (1) Function subprogram SA , calculates the solid angle element subtended at a point by a detector with circular aperture
- (2) Subroutine subprogram PHINT calculates the correction factor for the incident beam variation on the target
- (3) Subroutine subprogram LUM calculates the effect on the target surface from the incident beam variation
- (4) Subroutine subprogram PRID calculates by linear interpolation from input data the relative probability of an energy value of the emitted particle
- (5) Subroutine subprogram PHEN calculates the kinematics of a two body final state photoproduction reaction
- (6) Subroutine subprogram PHNBR calculates the number of photons per equivalent quanta

- (7) Subroutine subprogram EQAW approximates a distribution with a constant value distribution of the same area and calculates the mean value of the distribution.
- (8) Subroutine subprogram TRAJE calculates the length of the particle trajectory in the target volume of an emitted particle
- (9) Subroutine subprogram TRAJP plots the distribution of the trajectory lengths.

3.2 Input data

CARD 1 FORMAT(F7.1)

EOMAX

EOMAX The maximum available energy from the
 accelerator

CARD 2 FORMAT(5F5.3,I1)

DD, DX, DY, DRDX, DRDY, ITARG

DD, DX, DY Integration parameters (increments) in the
 target volume along d_0 -, x_0 - and y-axes
 respectively in cm

DRDX, DRDY Horizontal and vertical integration para-
 meters (increments) at the detector surface
 in cm

ITARG Calculation mode parameter

= 0 For acceptance calculations

= 1 For calculation of the distribution of
 the particle trajectory lengths in the
 target volume

CARD 3 FORMAT(I1)

IDENT

IDENT Calculation steering parameter
 = 1 Continue calculation and read the in-
 tensity distribution of the incident
 beam (CARD 4)

CARD 4 FORMAT(I5,2F5.2)

NBBIN,BMDO,BMYO

NBBIN The number of input values of the incident
 beam intensity distribution (including the
 centre of the beam)

BMDO d_o -coordinate of the centre of the beam in
 cm (> 0 for that half of the target that
 faces the detector and ≤ 0 for the oppo-
 site part)

BMYO x_o -coordinate of the centre of the beam in
 cm (> 0 above and ≤ 0 below the hori-
 zontal plane through the centre of the tar-
 get TCM)

CARD 5 FORMAT(8(F6.4,F4.2)

BMINT(I),DBC(I)

BMINT(I) The intensity values of the incident beam
 in relative units

DBC(I) The distances from the centre of the beam
 to the point where the intensity is
 BMINT(I) in cm

CARD 6 Identical with CARD 3

IDENT = 2 Continue calculation and read the
 mass values of the reacting particles
 (CARD 7)

CARD 7 FORMAT(3F8.3)

MB,MC,MD

MB,MC,MD The masses (in MeV) of the particles b, c and d in the photoproduction, reaction $\gamma + b \rightarrow c + d$ with c as the particle detected

CARD 8 Identical with CARD 3

IDENT = 3 Continue calculation and read the parameters for the experimental set-up (CARD 9)

CARD 9 FORMAT(F6.2,F4.1,3F6.3,F6.2)

TETAP,ANINT,RD,RB,RT,ZO

TETAP Angle between the incident beam direction and the direction from the centre of the target to the centre of the detector in degrees

ANINT The angular interval for plotting the acceptance of the lab-angle of particle c in degrees

RD Radius of the detector in cm

RB Radius of the ~~cross~~-section of the incident beam in cm

RT Radius of the target cylinder in cm

ZO Distance between the target centre and the centre of the detector in cm

CARD 10 Identical with CARD 3

IDENT = 4 Start of calculation of the angular acceptance of the experimental set-up

CARD 11 Identical with CARD 3

IDENT = 5 Continue calculation and read the energy distribution of the particles accepted in the detector (CARD 12)

CARD 12 FORMAT(6I5)

NOBIN,IEB1,NBPEN,INF1,INF2, INF3

NOBIN Label for energy-bin identification (arbitrary)

IEB1 ^{value}
Lowest energy (MeV) of the particles accepted
in the detector

NBPEN Number of energy bins (every bin width is
1 MeV) in the accepted particle energy
distribution in the detector

INF1 = 0 For plot of particle c's cm-angle
distribution

= 1 The plot is suppressed

INF2 = 0 For plot of particle d's cm-angle
distribution

= 1 The plot is suppressed

INF3 = 0 For plot of particle d's lab-energy
distribution

= 1 The plot is suppressed

CARD 13 FORMAT(16F5.1)

PRINT(I)

PRINT(I) Intensity distribution of the emitted particles
in relative units

CARD 14 Identical with CARD 3

IDENT = 6 Continue calculation and read the
end point energy of the bremsstrahlung
beam (CARD 15)

CARD 15 FORMAT(F6.1,I1)

EOK,ITAB

EOK The end point energy of the incident bremsstrahlung beam

ITAB = 0 For tabulation of acceptances of all
 photon energy values

 = 1 The tabulation is suppressed

CARD 16 Identical with CARD 3

IDENT = 7 End of calculation

By using a suitable value of the calculation steering parameter IDENT the calculation can be repeated with new input data or interrupted at any point desired.

3.3 Restrictions on input data

The restrictions on the input data are shown in the dimension statements at the program listing. The bremsstrahlung end point energy read from CARD 15 is maximized to 1200 MeV.

4. THE TEST RUNS

Two test runs corresponding to the two calculation modes were performed. Test run 1 for calculation of effective target thickness, effective solid angle, angle and energy acceptances etc was executed with the following input data:

CARD 1 EOMAX = 1200.

CARD 2 DD=.2, DX=.1, DY=.2, DRDX=1.0, DRDY=1.0,
 ITARG=0

CARD 3 IDENT=1

CARD 4 NBBIN=2, BMDO=.0, BMYO=.0

CARD 5 BMINT(1)=1.00, DBC(1)=.0, BMINT(2)=0.20,
 DBC(2)=3.50

CARD 6 IDENT=2

CARD 7 MB=938.26, MC=938.26, MD=137.975

CARD 8 IDENT=3

CARD 9 TETAP=24.0, ANINT=0.1, RD=3.003,
 RB=1.650, RT=3.25, ZO=129.90

CARD 10 IDENT=4

CARD 11 IDENT=5

CARD 12 NOBIN=103, IEB1=93, NBPEN=18, INF1=0,
 INF2=0, INF3=0

CARD 13a PRINT(1), PRINT(2),...PRINT(16)=1.0,3.0,5.0,
 7.0,9.0,11.0,13.0,15.0,17.0,19.0,17.0,15.0,
 13.0,11.0,8.0,6.0

CARD 13b PRINT(17)=4.0, PRINT(18)=2.0

CARD 14 IDENT=6

CARD 15 EOK=445

CARD 16 IDENT=7

Test run 2 for calculation of the distribution of the
length of the trajectories in the target volume was
executed with the following cards:

CARD 1 EOMAX=1200,

CARD 2 DD=.05, DX=.05, DY=.15, DRTX=1.5, DRTY=1.5,
 ITARG=1

CARD 3 IDENT=1

CARD 4 NBBIN=2, BMDO=.0, BMYO=.0

CARD 5 BMINT(1)=1.0, DBC(1)=.0, BMINT(2)=0.2,
DBC(2)=3.50

CARD 6 IDENT=3

CARD 7 TETAP=24.0, ANINT=0.1, RD=3.003, RB=1.650,
RT=3.250, ZO=129.90

CARD 8 IDENT=4

CARD 9 IDENT=7

ACKNOWLEDGEMENTS

The author wishes to express his thanks to P Dougan, K Lugné, W Ramsay and W Stiefler for useful discussions and criticism when preparing the manuscript, to professor G von Dardel for his encouragement and interest and to Mrs I Hammar for her excellent typing work.

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- [4] L I Schiff, Phys Rev 83 (1951) 252.

FIGURE CAPTIONS

- Figure 1. Summary of notations used.
- Figure 2. Chart showing the general principles of the calculation procedures.
- Figure 3. Definition of parameters for calculation of the solid angle element.
- Figure 4. Horizontal cut through the centres of the target and the detector showing the parameters used for calculation of the angular acceptance.
- Figure 5. Definition of parameters for calculation of an angle element and its probability.
- Figure 6. Definition of parameters for calculation of the trajectory length in the target volume.
- Figure 7-12. The computer output list.

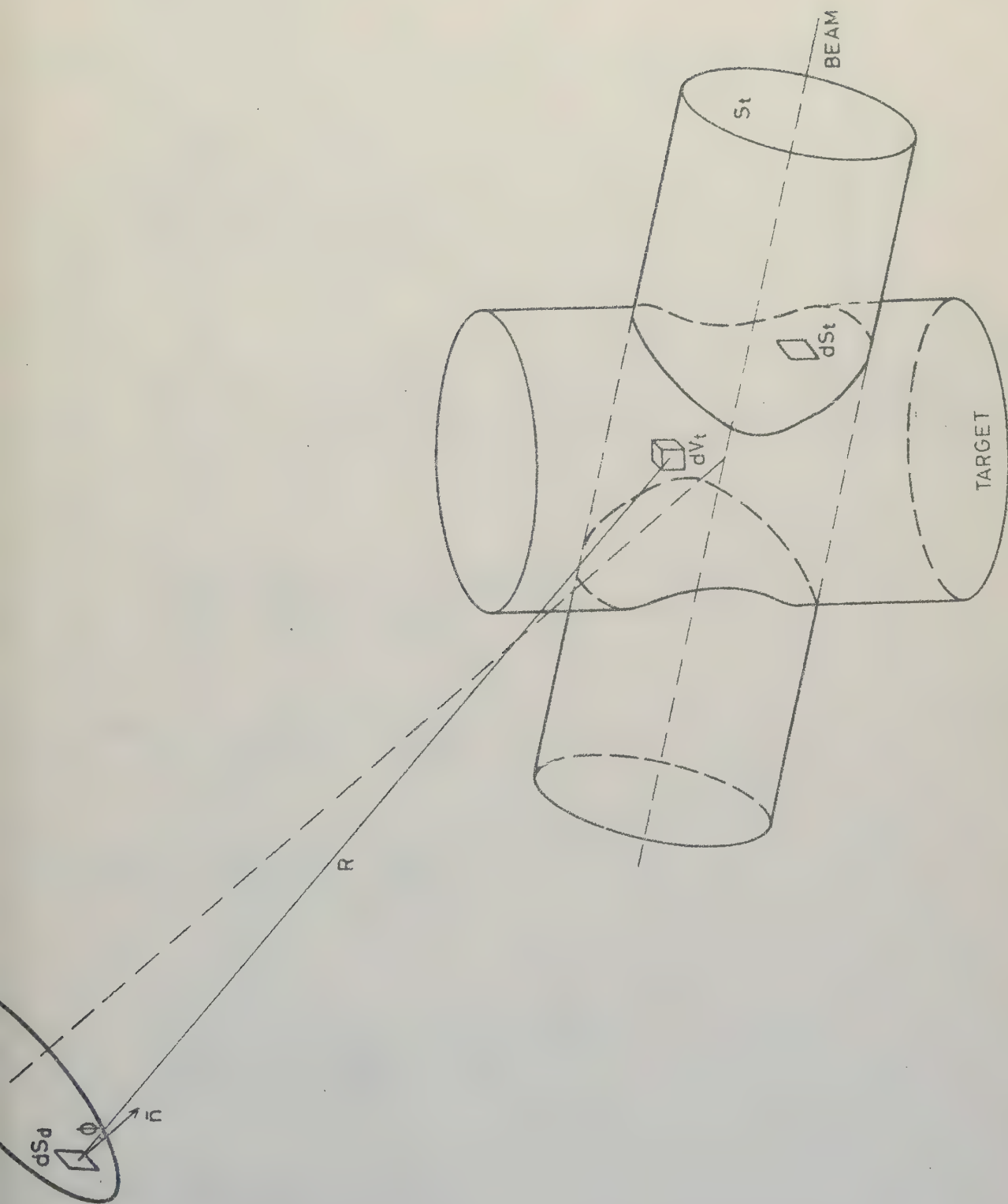
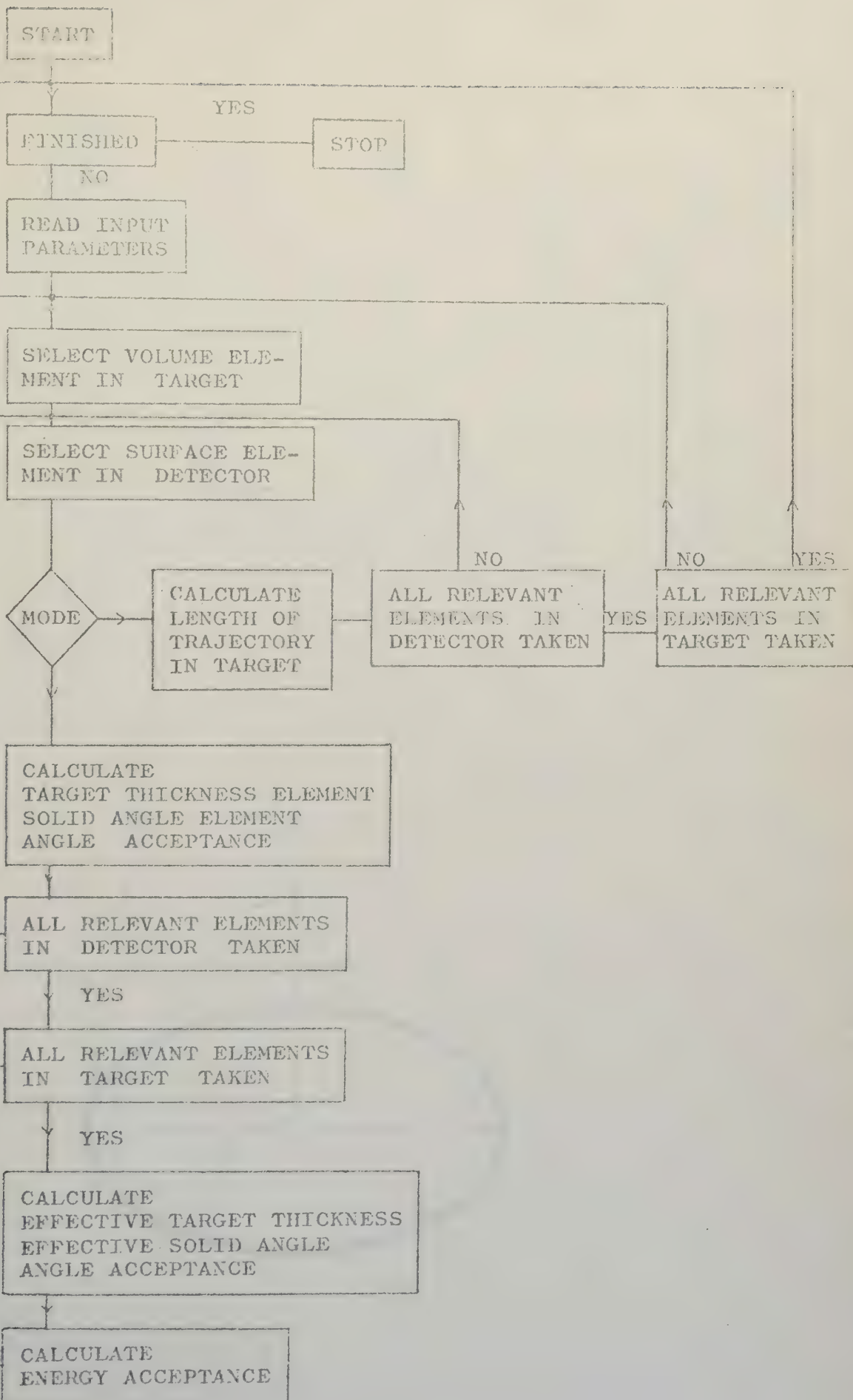


FIGURE 1



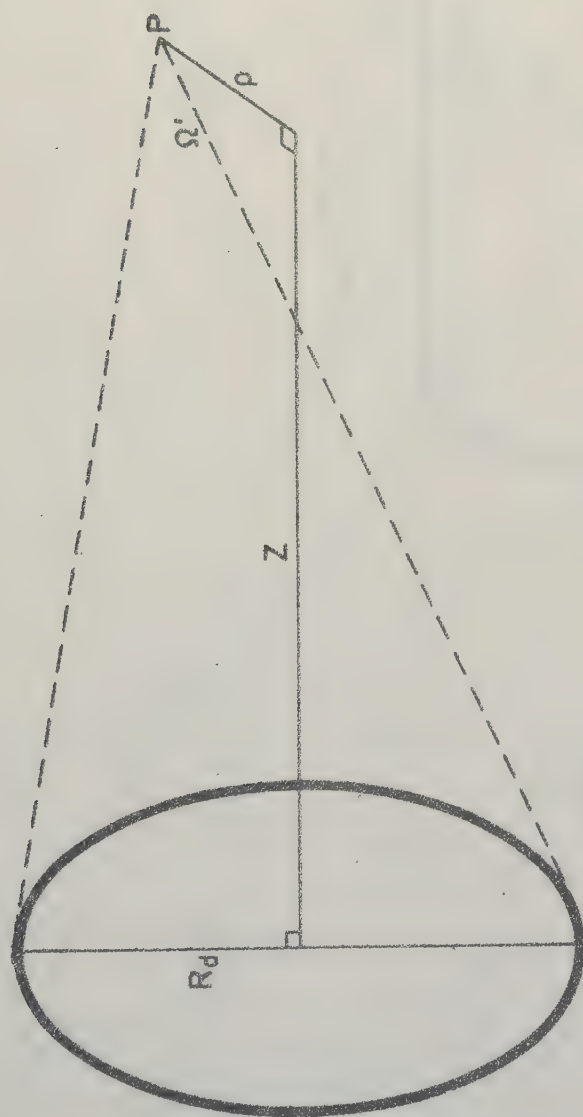


FIGURE 3

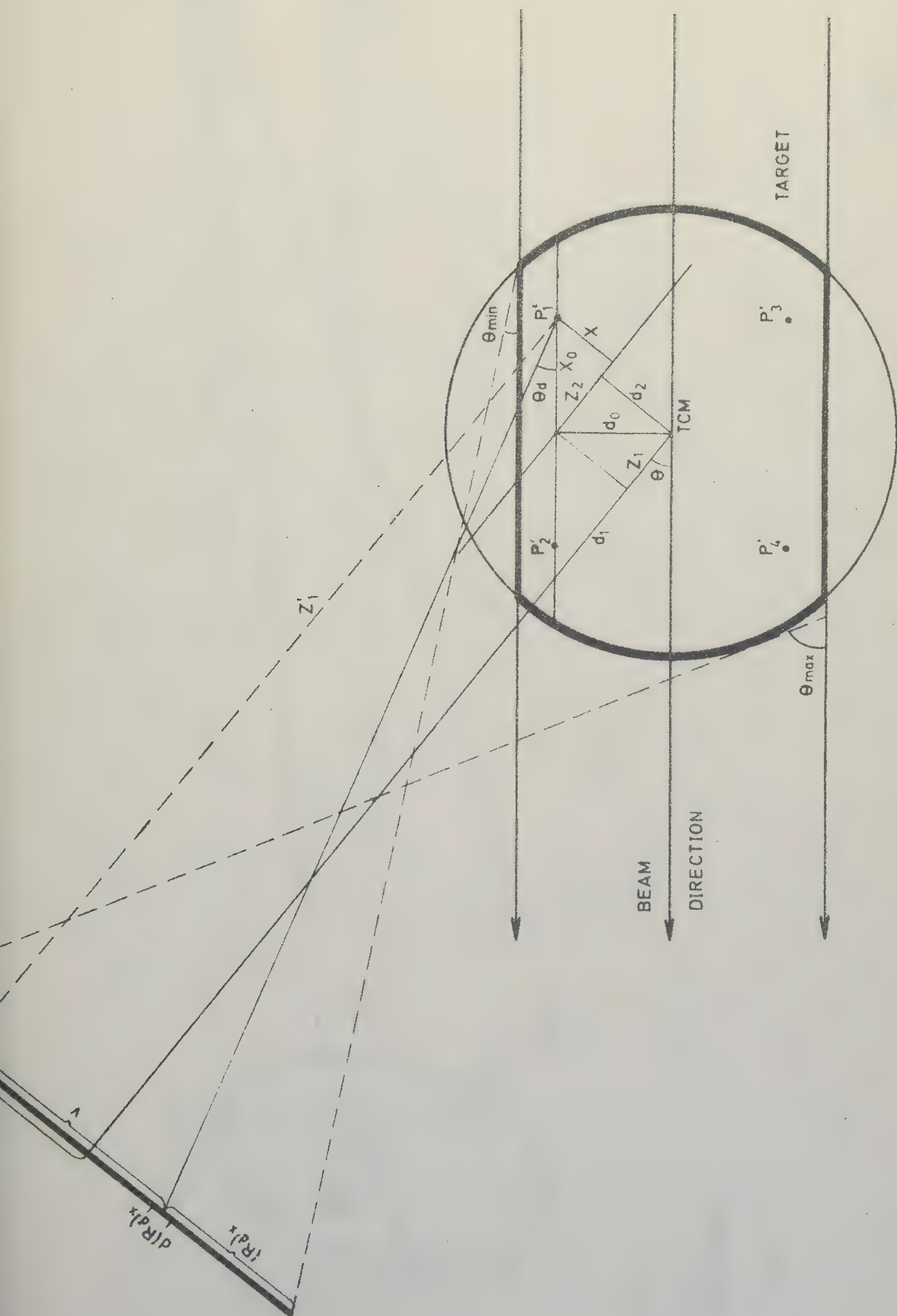


FIGURE 4

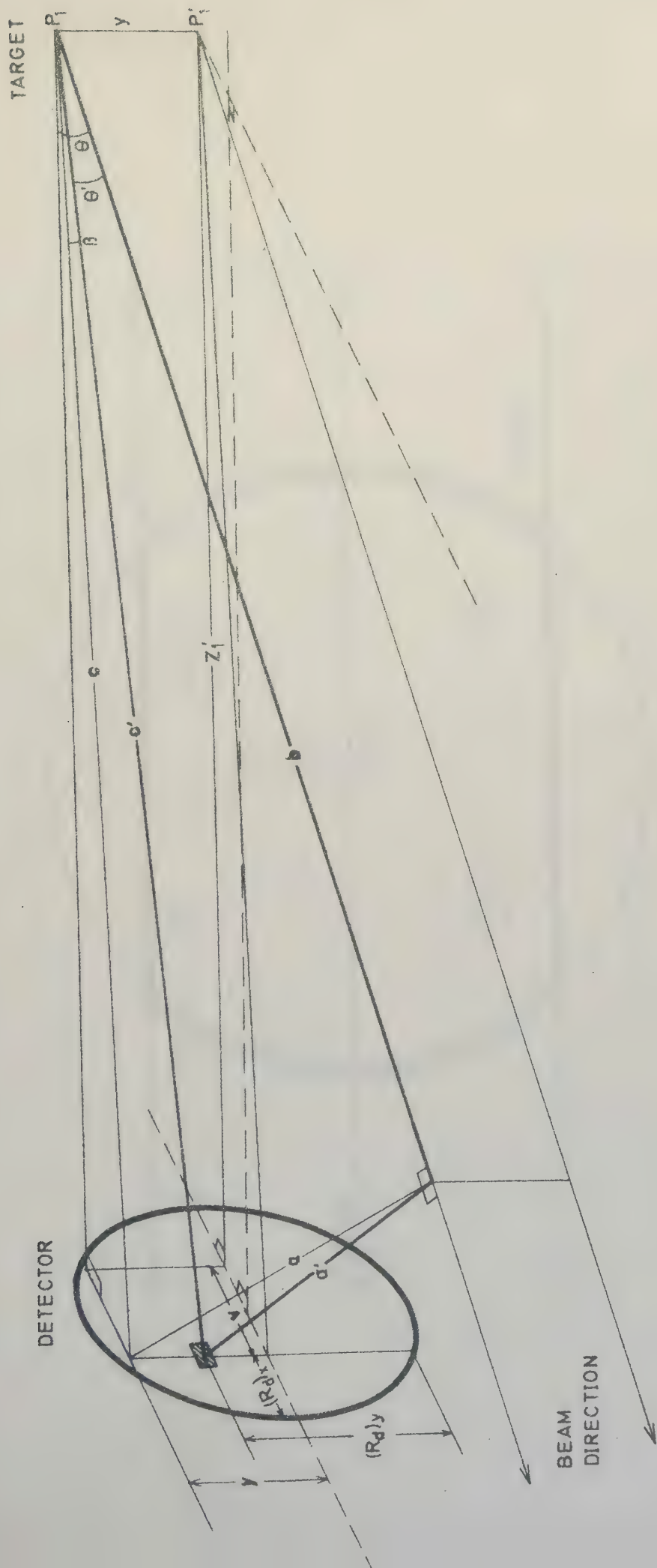


FIGURE 5

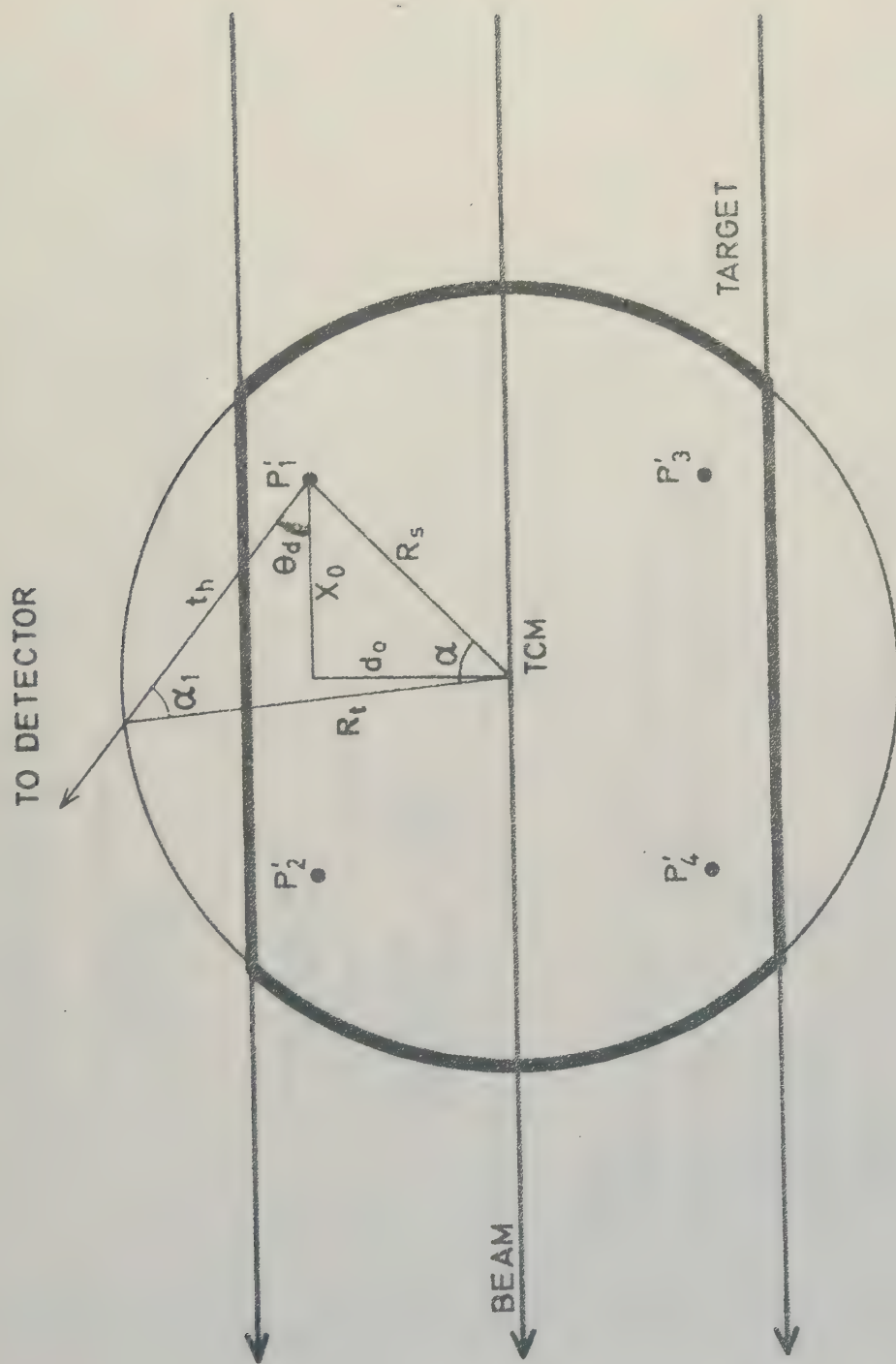


FIGURE 6

ACCEPTANCE CALCULATIONS FOR THE REACTION A+B -> C+D

A IS THE INCIDENT PARTICLE (PHOTON)
B IS THE TARGET PARTICLE (AT REST)
C IS THE DETECTED PARTICLE
D IS A PARTICLE NOT DETECTED IN COINCIDENCE

THE CALCULATION IS PERFORMED FOR

W1 = 938.260 MEV
W2 = 938.260 MEV
W3 = 137.975 MEV

MAXIMUM ACCELERATOR ENERGY = 1200.0 MEV

EXPERIMENTAL SET UP

DETECTOR ANGLE 24.00 DEGREES

DETECTOR RADIUS 3.00 CM
BEAM RADIUS 1.65 CM
TARGET RADIUS 3.25 CM
DETECTOR DISTANCE 129.9 CM

INTEGRATION PARAMETERS TARGET DD = .200 DX = .100 DY = .200 CM
DETECTOR DRDX = 1.000 DRDY = 1.000 CM

RESULTS

SOLID ANGLE = 1.67885 MILLIRADIANS
NUMBER OF INTEGRATIONS = 15272

ANGULAR REGION = 0

MAXIMUM ELEMENT = 1.70114 COORDINATES J = 1 I = 31 K = 1 IDMAX = 3
MINIMUM ELEMENT = .99718 COORDINATES J = 6 I = 30 K = 7 IDMIN = 5

SOLID ANGLE AT CM = 1.67826
SOLANG-SOLANGCME = .00059
SOLANG-SOLANGMAX = -.02229
SOLANG-SOLANGMIN = .68167
SOLANGMAX-SOLANGMIN = .70397

IRRADIATED VOLUME OF THE TARGET = 53.8911 CCM

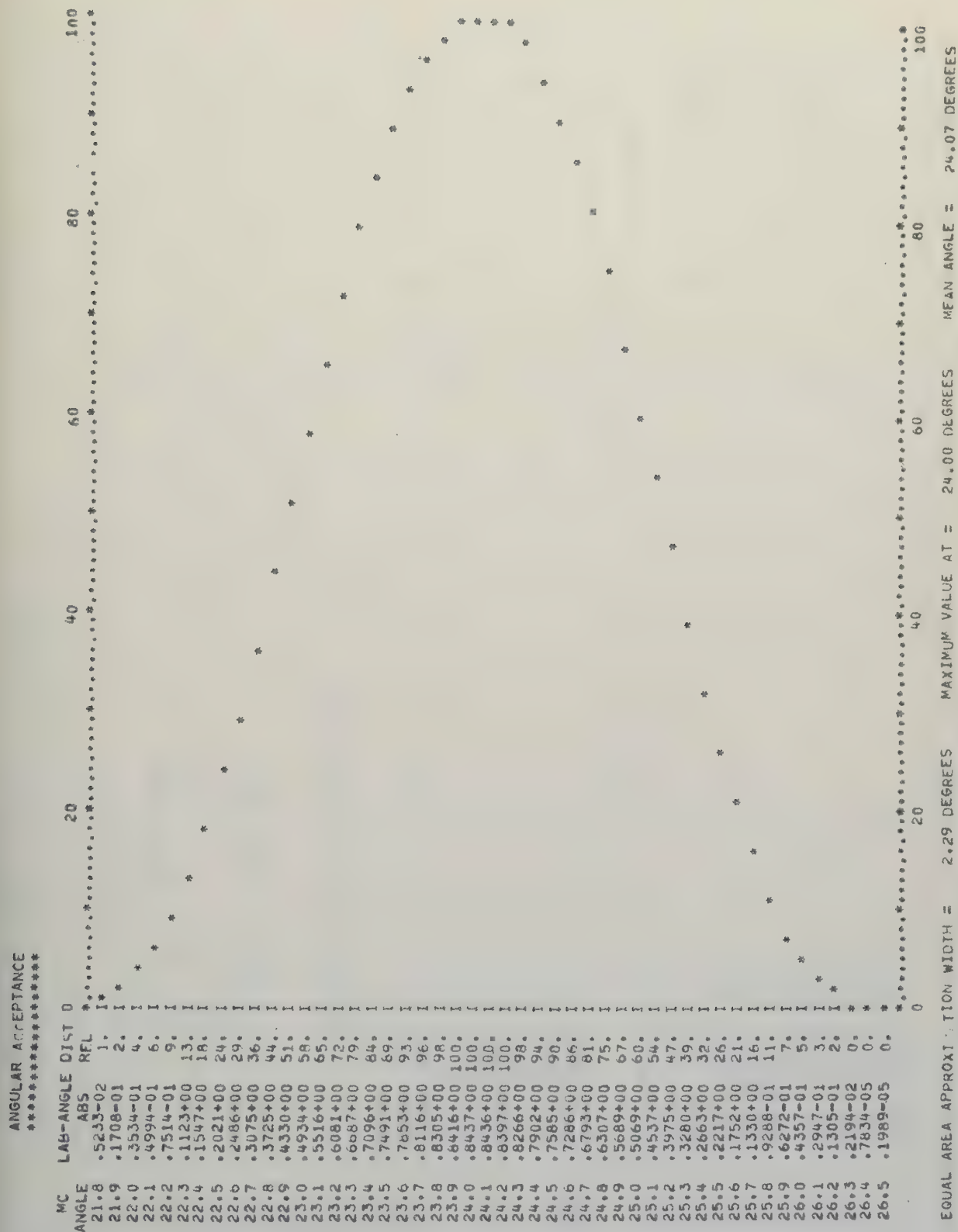
IRRADIATED VOLUME OF TARGET MULTIPLIED BY INTENSITY = 40.4321

GEOMETRICAL TARGET SURFACE = 8.553 SCM
INTENSITY MULTIPLIED TARGET SURFACE = 6.517
MEAN INTENSITY AT TARGET SURFACE = .762

GEOMETRICAL TARGET THICKNESS = 6.301 CM
EFFECTIVE TARGET THICKNESS = 6.204 CM .984% OF GEOMETRICAL VALUE

BEAM INTENSITY DISTRIBUTION BEAM CENTRE AT D0 .00 AND Y .00
INTENSITY (DIST IN CM FROM THE BEAM CENTRE)

1.000 (.00) .200 (3.50)



FIGURE

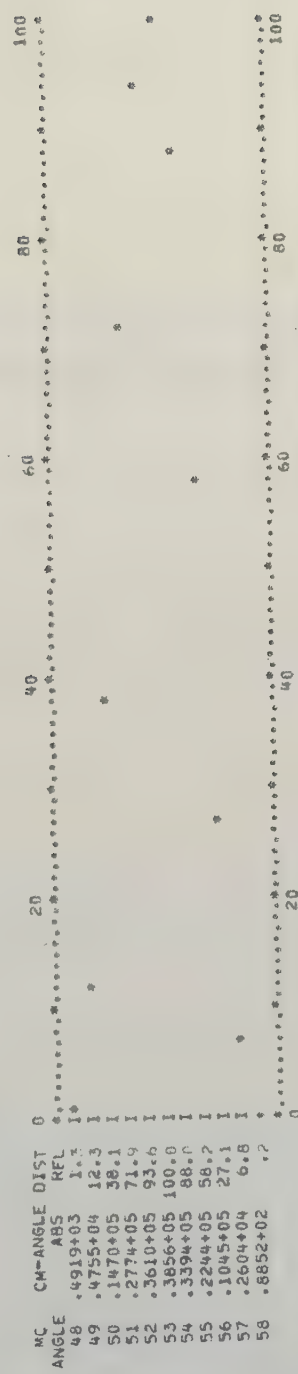
ANGLE AND ENERGY DISTRIBUTIONS

 CALCULATION FOR THE ENERGY BIN 103
 THE INTENSITY DISTRIBUTION OF MC LAB-ENERGY (INTENSITY)
 101(2.0) 102(3.0) 103(5.0) 104(7.0) 105(9.0) 106(11.0) 107(13.0) 108(15.0) 109(17.0) 110(17.0)
 111(16.0) 112(14.0) 113(12.0) 114(10.0) 115(8.0) 116(6.0) 117(4.0) 118(2.0)
 EQUAL AREA APPROXIMATION WIDTH = 10.06 MEV MEAN LAB ENERGY = 110.21 MEV

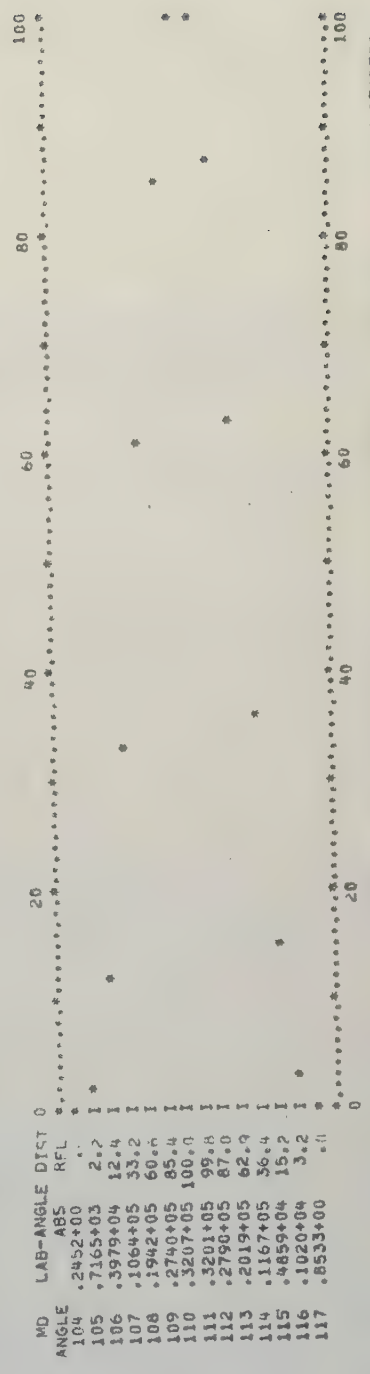
MEAN VALUES OF ENERGY AND ANGLE

	ENERGY (MEV)	ANGLE (DEGREES)
MA	354.9	67.8
MB	0	0
MC	109.5	29.8
MD	107.4	137.5

CROSS-SECTION TRANSFORMATION FACTOR .2325
 MC ENERGY INTERVAL FOR EACH CALCULATION = .017 MEV



EQUAL AREA APPROXIMATION WIDTH = 4.98 DEGREES MAXIMUM VALUE AT = 53.00 DEGREES MEAN ANGLE = 53.32 DEGREES



EQUAL AREA APPROXIMATION WIDTH = 5.98 DEGREES MAXIMUM VALUE AT = 110.00 DEGREES MEAN ANGLE = 111.05 DEGREES



MINIMUM ACCEPTED PHOTON ENERGY 332.2 MEV
 CORRESPONDING MD LAB ENERGY 93.2 MEV LAB ANGLE 116.51 DEGREES
 MAXIMUM ACCEPTED PHOTON ENERGY 380.3 MEV
 CORRESPONDING MD LAB ENERGY 124.3 MEV LAB ANGLE 103.98 DEGREES
 MINIMUM PHOTON ENERGY ACCEPTED BY THE HODOSCOPE FOR EXTRA PION PRODUCTION 420.5 MEV

PHOTON ENERGY (MEV) REL EOK	NUMBER OF PHOTONS SCHIFF SPECTRUM	PHOTON ACCEPTANCE IN HODOSCOPE	RELATIVE RESPONSE IN HODOSCOPE	NUMBER OF INTERACTING PHOTONS
332 .74667	.00270	.2	.000016	.425813-07
333 .74831	.00269	5.5	.000565	.152010-05
334 .75056	.00268	28.8	.002934	.786705-05
335 .75281	.00267	89.9	.009172	.245194-04
336 .75506	.00267	205.7	.020978	.559219-04
337 .75730	.00266	395.2	.040306	.107142-03
338 .75955	.00265	667.3	.068067	.180428-03
339 .76180	.00264	1024.6	.104506	.276243-03
340 .76404	.00264	1457.3	.148637	.391800-03
341 .76629	.00263	1972.2	.201157	.528771-03
342 .76854	.00262	2555.9	.260693	.683381-03
343 .77079	.00261	3181.6	.324513	.849347-03
344 .77303	.00261	3834.7	.391135	.101972-02
345 .77528	.00260	4511.2	.460134	.119636-02
346 .77753	.00259	5232.3	.533678	.138383-02
347 .77978	.00259	5916.4	.603461	.156058-02
348 .78202	.00258	6605.0	.673693	.173755-02
349 .78427	.00257	7286.4	.743201	.191172-02
350 .78652	.00257	7972.9	.813219	.208630-02
351 .78876	.00256	8553.3	.872420	.223229-02
352 .79101	.00255	9036.0	.921655	.235209-02
353 .79326	.00255	9428.9	.961726	.244795-02
354 .79551	.00254	9674.4	.986771	.250519-02
355 .79775	.00253	9804.1	1.000000	.253222-02
356 .80000	.00253	9725.3	.991954	.250538-02
357 .80225	.00252	9538.3	.972889	.245094-02
358 .80449	.00251	9165.0	.934609	.234901-02
359 .80674	.00251	8720.4	.889464	.222939-02
360 .80899	.00250	8184.4	.834788	.208786-02
361 .81124	.00249	7560.6	.771164	.192313-02
362 .81349	.00249	6900.5	.703836	.175083-02
363 .81573	.00248	6156.9	.627990	.155825-02
364 .81798	.00248	5486.5	.559608	.138511-02
365 .82022	.00247	4746.8	.484160	.119539-02
366 .82247	.00246	4008.8	.408884	.108704-02
367 .82472	.00246	3312.4	.337861	.830063-03
368 .82697	.00245	2648.5	.270146	.662066-03
369 .82921	.00244	2029.9	.207049	.506185-03
370 .83146	.00244	1518.0	.154836	.377609-03
371 .83371	.00243	1067.3	.108860	.264837-03
372 .83596	.00243	721.4	.073585	.178584-03
373 .83820	.00242	450.1	.045908	.111142-03
374 .84045	.00242	258.8	.026397	.637526-04
375 .84270	.00241	134.4	.013708	.330253-04
376 .84494	.00240	59.8	.006102	.146649-04
377 .84719	.00240	22.6	.002302	.551854-05
378 .84944	.00239	6.2	.000637	.152238-05
379 .85169	.00239	.6	.000058	.138422-06
380 .85393	.00238	.0	.000000	.750833-10

TOTAL NUMBER OF INTERACTING PHOTONS = .495624-01 FOR SYNCHROTRON ENERGY = 445.0 MEV
 EQUAL AREA APPROXIMATION WIDTH = 19.6 MEV MAXIMUM VALUE AT = 345.0 MEV MEAN ENERGY = 354.5 MEV

EXPERIMENTAL SET UP

DETECTOR ANGLE 24.00 DEGREES

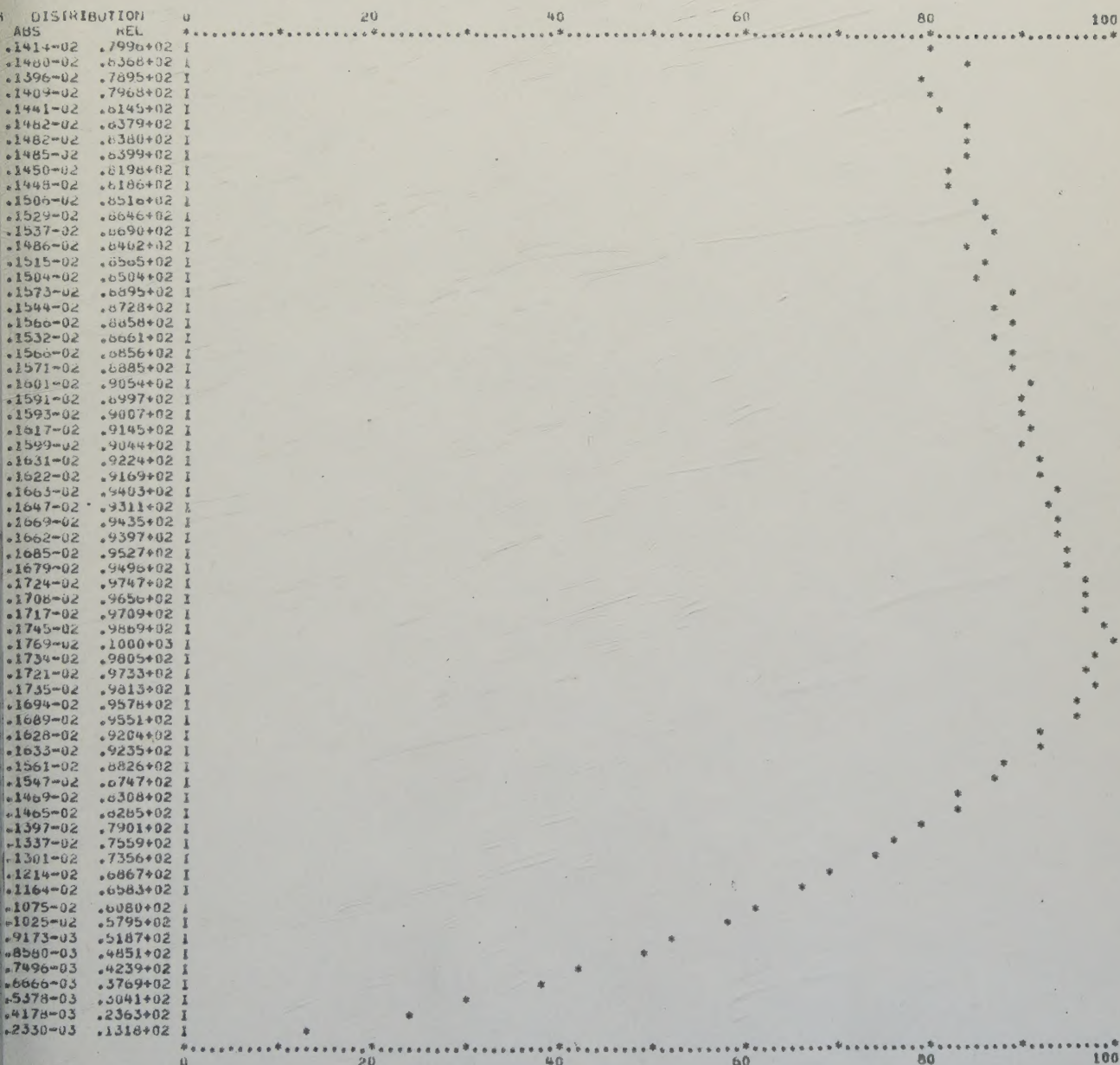
DETECTOR RADIUS 3.00 CM
BLANK RADIUS 1.65 CM
TARGET RADIUS 3.25 CM
DETECTOR DISTANCE 129.9 CM

BEAM INTENSITY DISTRIBUTION BEAM CENTRE AT X0 .00 AND Y .00
INTENSITY (DIST IN CM FROM THE BEAM CENTRE)

.00) 1.000(3.50)

INTEGRATION PARAMETERS TARGET DD = .050 UX = .050 DY = .150 CM
DETECTOR DRDX = 1.500 DRDY = 1.500 CM

DISTRIBUTION OF PARTICLE TRAJECTORY LENGTHS IN THE TARGET VOLUME



MEAN LENGTH = .3083+02 MM

